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I, JULIE BILLINGSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2002952687 for a patent by IN MOTION TECHNOLOGIES PTY LTD as filed on 15 November 2002.

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AUSTRALIA

PATENTS ACT 1990

PROVISIONAL SPECIFICATION

FOR THE INVENTION ENTITLED:-

"POLY-PHASE ELECTROMAGNETIC DEVICE HAVING AN IMPROVED CONDUCTOR WINDING ARRANGEMENT"

The invention is described in the following statement:-

Introduction

The present invention relates to poly-phase electromagnetic devices such as motors, generators and transformers, of the kind that employ a toothed or slotted magnetically conducive structure into which an electrically conductive winding is wound.

The invention has been developed primarily for use in axial flux motors and will be described in detail in reference to this application. However, it will be appreciated by those skilled in the art that the inventive principles are equally applicable to radial flux motors or generators and indeed any other electromagnetic device that includes a slotted magnetically conducive structure into which a conducive winding is wound.

Any discussion of the prior art throughout the specification should in no way be considered as an admission that such prior art is widely known or forms part of common general knowledge in the field.

Background

When trying to optimise the power to size and/or weight ratio of a poly-phase electromagnetic device such as a motor of the kind described above, the packing and spacing of the electrical conductor phase windings within the magnetically conducive base is an important factor. In this regard the use of a magnetically conducive base within which to restrain the magnetic flux has the known advantages of effectively concentrating the magnetic field. This improves functionality of the motor due to a higher concentration of magnetic flux, at the same time reducing the precision necessary for machining and operating tolerances.

In order to optimise the power density of the device, it is desirable to have a base and winding configuration that is capable of minimising the size and mass of the

magnetically conducive base that is required. This in turn will reduce the cost of the device through reduction in construction materials.

This has been a particular problem with, for example, known three phase motors where the phase windings are wound in a wave or lap form progressively one upon the other with each phase offset. This results in uneven slot packing due to physical interference of separate phase windings in the region between slots, known as the end turn, as in some places there must be three windings occupying the same end turn space. This means the slots and base must be sized to accommodate three windings even though those slots will only need to house one winding, resulting in redundant mass and material in the base. Further, the non-active end turns of such an arrangement have to be fairly long because of the increased slot depth and uneven packing in each slot. This results in bulky end turns that make it difficult to adapt such motors for use where housing space is minimal. Further, it is a waste of expensive conductor winding materials and also has significant negative impact on operational efficiency due to unnecessary Ohmic heating in the lengthened conductors. An alternative method is also employed where extremely long non-active end turns are employed, allowing enough room for each end turn to completely clear the others and simultaneously filling the slot completely, however the prohibitively long end turn employed in this case causes the same material wastage and efficiency problems as those mentioned with the previous technique.

One solution proposed by the applicant has been to provide a three phase, multiple conductor strand, wave winding arrangement for an axial flux motor that achieves a maximum of two phase end turn overlaps between slots, thus giving reduced end turn lengths around the majority of motor periphery. However, this arrangement still requires external joining of the multiple conductor strands at the ends of each phase

winding. This inevitably results in a series of bulging connections that extend radially beyond the rest of the windings at one location, again making efficient packaging of the motor almost impossible. Further the process is very labour intensive and not suited to any convenient form of automation which in turn adversely affects the economic viability of such a design.

It is an object of the present invention to overcome or ameliorate one or more of the discussed disadvantages of the prior art, or provide a useful alternative.

Summary of the Invention

According to a first aspect of the invention there is provided a poly-phase electromagnetic device having n winding phases (where n is greater than 2), said device including:

n separate electrical conductor phase windings, each phase winding being made from two or more coextending electrical conductor strands;

a magnetically conducive base having a plurality of slots adapted to receive active portions of the phase windings therein;

each said phase winding comprising a series of interconnected lap form sub-windings, with each sub-winding defining two active arms that extend through two spaced apart non-adjacent slots in the base joined by suitably formed end turns and two connecting arms for connection with adjacent sub-windings or terminals;

wherein said phase windings are configured such that on assembly of the phase windings to the magnetically conducive base there is a maximum of n-1 sub-winding end turns overlapping, while the lengths of the end turns are simultaneously minimised.

In a preferred form the device has three phase windings each made from lap form sub-windings with alternative sub-windings being wound in opposite directions, with the

completed phase windings intertwined in a plait like configuration to achieve the n-1 end turn packing configuration.

Preferably, the connecting arms are configured to extend within gaps formed closely adjacent the magnetically conducive base.

In a first form, the lap form sub-windings are manufactured in the form of discrete bobbins comprising a multiple of conductor strand turns with connection points at each end for joining with an adjacent bobbin of the same phase. In an alternative form the lap form phase windings are formed from a continuous length of conductor strand to form interconnected lap sub-windings which is particularly suited to mass production techniques.

According to a second embodiment of the invention there is provided a poly-phase electromagnetic device having n winding phases (where n is greater than 2), said device including:

n separate electrical conductor phase windings, each phase winding being made from a single electrical conductor strand;

a magnetically conducive base having a plurality of slots adapted to receive active portions of the phase windings therein;

each said phase winding comprising a series of spaced active arms that extend through spaced apart non-adjacent slots in the base, each active arm being connected with an end turn or terminal in a continuous wave formation;

wherein said phase windings are configured such that an assembly of the phase windings to the magnetically conducive base there is a maximum of n-1 sub-winding end turns overlapping while simultaneously minimising the lengths of the end turns.

Preferably, the phase windings are intertwined in a plait like configuration to achieve the n-1 end turn packing configuration.

In a preferred form, each phase winding is made as a single thickness pressing from sheet conductor material.

In a preferred form, the poly-phase electromagnetic device comprises a three phase axial flux motor or generator.

Brief Description of the Drawings

Preferred embodiments of the invention will now be described by way of example only, with reference to the accompanying drawings in which :

Figure 1 is a photograph of a prior art three phase multiple conductor strand axial flux stator with n-1 overlap wave winding showing the bulging conductor strand end joins;

Figure 2 is a schematic illustration of a common prior art three phase winding arrangement;

Figure 3 is a photograph of a first embodiment three phase, axial flux stator which has been wound according to a first aspect of this invention;

Figure 4 is a schematic illustration of an n-1 overlap winding arrangement according to the invention;

Figure 5 is a computer generated illustration of the stator shown in Figure 3 for clarity;

Figure 6 is a computer generated illustration of the slotted magnetically conducive base of the stator shown in Figure 5, without the three phase winding;

Figure 7 is a computer generated illustration showing only the three phase winding of Figure 5, without the magnetically conducive base;

Figure 8 is a computer generated illustration of two examples of lap form sub-winding or "bobbin" as would be employed in the example of Figure 5 having opposite winding directions;

Figure 9 is a computer generated illustration of several intertwined bobbins, indicating the relative positions of the bobbins, as would be employed in the example of Figure 5;

Figure 10 is a computer generated illustration of one of three single complete phase windings, without showing end terminations, as would be employed in the example of Figure 5;

Figure 11 is a computer generated illustration of another embodiment made in accordance with a second aspect of the invention, with only a single conductor strand employed for each phase winding, negating the need for end joins;

Figure 12 is a computer generated illustration of one of three complete phase windings, without showing end terminations, as would be employed in the example of Figure 11.

Detailed Description of the Invention

Figure 1 shows a complete prior art three phase axial flux motor/generator stator having a wave winding configuration showing the problems with bulging connections 1 where the multiple strands of each phase winding are joined. The increase in radius of the stator is clearly visible at this point. This is a distinct disadvantage with this form of motor winding, increasing the level of shaft concentric diametric clearance required around the motor and at the same time increasing the cost and size of any casing that might be used. The windings produced are also extremely complex, typically requiring CNC manufacture from copper plate which is expensive and wasteful or jig winding with a high degree of complexity, as many different bends of different radius are required. As an added level of complexity, once a winding is complete each turn needs to be end joined, which requires marking each individual end and ensuring that appropriate ends are joined together. Automation of this process is extremely difficult.

Figure 2 is a schematic diagram which shows the most common prior art method used for stacking a three phase winding within a slotted magnetically conducive base, the diagram being simplified by showing linear motor/generator stator rather than an axial flux or radial flux stator. The diagram shows three phases 2, 3 & 4, and slotted magnetically conducive base 5. The end turn region defined by 6 shows the area where all three phase end turns overlap. Due to all three phases interfering or overlapping in this region, this is defined as a conventional n phase n overlap winding system. As can be seen from the diagram, only a small amount of winding cross section fits into the slot area so slot packing density is very low. An alternative prior art method employs extremely elongated end turns which may be overlapped without compromising on slot packing density, however this method suffers from an increased material requirement and Ohmic heating losses in the elongated end turns. While these methods for stacking a winding within slots are very simple to construct with each winding being wound separately on top of the previous, they do not lend themselves to an efficient design in terms of either materials use or electrical efficiency.

Figure 4 is a simplified diagram in the same style as Figure 2, however showing an improved winding stacking arrangement in accordance with a part of this invention, whereby end turn interference is reduced. The diagram shows that only two end turns interfere with each other in the three phase system, hence n-1 overlaps in n phases.

Figure 3 shows a complete three phase axial flux motor/generator stator in accordance with the first aspect of the invention. The conductive winding inserted into the slotted magnetically conducive base 5 can be constructed by several methods. The first method is to construct separate lap elements or "bobbins" comprised of a lap winding each with trailing ends. Half of these elements are wound in a forward winding direction and half in a reversed direction. The reversed lap winding elements are then

placed next to each other in the slotted magnetically conducive structure. The forward wound lap winding elements are then stacked in the remaining free slots on top of the reverse wound lap winding elements, in a mirrored fashion. The trailing ends of the bobbins within each phase are then interconnected to form end joins, one end of each of the phases connected together to form a star point and the remaining ends left free as the motor / generator termination point. End joins are required both at the top of the structure 7 and at the bottom of the structure 8.

Figure 5 shows a computer generated model of the first aspect of the invention as shown in Figure 3. For clarity, each of the three separate phases is shown in a different shade of grey. Upper 9 and lower 10 end joins are shown as in Figure 3. For simplicity, the windings have a rectangular cross section which reflects the envelope that would typically contain multiple loops of conductor strand.

Figure 6 shows only the magnetically conducive base portion of Figure 5, with the windings removed. The slots in the structure can be clearly seen in this illustration.

Figure 7 shows only the three phase winding portion of Figure 5, not showing the magnetically conducive base. As in Figure 5, each of the three separate phases 11, 12, 13 are shown in a different shade of grey.

Figure 8 shows two types of single lap form sub-windings or "bobbins" which suit the embodiment shown in Figures 3 & 5. The two lap elements shown are wound in opposite directions and are not identical, also called an upper and lower bobbin. Whilst end turn bend directions are the same for the two bobbins, the position of the connecting arms is reversed to suit the reversed winding direction. Each bobbin is formed of two or more coextending electrical conductor strands, however the simplified computer generated diagram only shows the envelope which would enclose those strands. Each sub-winding defines two active arms 14 that extend through two spaced apart non

adjacent slots when placed within the base, joined by suitably formed end turns 15 and two connecting arms for connection with adjacent sub-windings or terminals 16. Preferably the end turns for a lower bobbin both bend downward and the end turn for an upper bobbin both bend upward, Ideally the connecting arms do not extend directly radially outwardly, as this would interfere with the end turns. Instead, the arms extend generally axially upward or downward to fit neatly into gaps formed between the end turn and the base to help control the overall packing volume of the device. Figure 9 is a close-up diagram of a portion of Figure 7, showing only four bobbins. This diagram is included to indicate the relative positioning of each bobbin with respect to adjacent bobbins. Two bobbins 17 in this Figure are of the same phase winding and are therefore connected 18.

Figure 10 shows a single complete phase winding which suits the embodiment shown in Figures 3 & 5. This particular winding is comprised of four upper and four lower bobbins and does not show winding terminations for the sake of simplicity. When a completed winding such as the one demonstrated in Figure 10 is to be manufactured by the aforementioned method with discrete bobbins, then eight separate bobbins are required and must be each electrically end joined by a method such as crimping and soldering. Typically, these end joins would be prepared once the bobbins had been inserted into the slotted magnetically conducive base.

Using the second method, the lap elements are wound without stopping to form three complete phases. These phases are thus continuously wound without electrical interconnection required, negating the need to end join. The phases may be wound directly into the magnetically conducive slotted base in order to reduce cost, known as direct winding, or wound separately on a jig and plaited together to form a complete

winding, which is then inserted into the slotted magnetically conducive base. Windings formed in this manner more closely resemble the illustration of Figure 10.

The last method and structure refers to lap windings with only a single conductor in each lap, whereby only a single strand of conductor is used rather than two or more coexisting strands. These can be easily manufactured by a drop forging pressing or similar methods. Windings formed in this manner can be known as single turn windings, do not require end joining, and look like the axial flux example shown in Figure 11. This method has advantages in special cases which require high current, torque and/or efficiency, along with simple manufacturing. The windings can either be formed separately for simplicity, since all three windings are the same, or all three formed simultaneously incorporating a star point and termination points at the same time. An example of an individual winding formed using this process is shown by illustration in Figure 12. Note that whilst bobbins are not required for this winding, an "end join region" is still needed to overlap other phases, and this end join region still needs to be bent either up or down to form the required clearances.

Whilst the invention has been described with reference to specific examples of axial flux motors, it will be appreciated by those skilled in the art that the various aspects of the invention may be embodied in many other forms. In particular the invention suits the common radial flux motor/generator geometry in both internal and external rotor variants. The invention can be equally applied to transformer windings in situations where the improved packing density is desirable. In all cases, the invention applies to n phase systems where n is greater than 2 and a conductive winding is wound into a magnetically conducive base.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:-

1. A poly-phase electromagnetic device having n winding phases (where n is greater than 2), said device including n separate electrical conductor phase windings, each phase winding being made from two or more coextending electrical conductor strands; a magnetically conducive base having a plurality of slots adapted to receive active portions of the phase windings therein; each said phase winding comprising a series of interconnected lap form sub-windings, with each sub-winding defining two active arms that extend through two spaced apart non-adjacent slots in the base joined by suitably formed end turns and two connecting arms for connection with adjacent sub-windings or terminals; wherein said phase windings are configured such that on assembly of the phase windings to the magnetically conducive base there is a maximum of n-1 sub-winding end turns overlapping, while the lengths of the end turns are simultaneously minimised.

2. A device according to claim 1 wherein one or more adjacent lap form sub-windings are wound in opposite directions.

3. A device according to claim 1 or claim 2 that has three phase windings each made from lap form sub-windings with alternative sub-windings being wound in opposite directions.

4. A device according to any one of the preceding claims where the connecting arms are configured to extend within gaps formed closely adjacent the magnetically conducive base.

5. A device according to any one of the preceding claims wherein the lap form sub-windings are manufactured in the form of discrete bobbins comprising a multiple of conductor strand turns with connecting arms at each end for joining with an adjacent bobbin of the same phase.

6. A device according to any one of claims 1 to 4 wherein the lap form sub-windings are formed from a continuous length of conductor strand to form interconnected lap sub-windings.

7. A device according to any one of the preceding claims wherein n phases are intertwined together in a plait like configuration to achieve n-1 end join overlaps.

8. A lap form subwinding according to claim 2 wherein connecting arms are located at different corners for a reverse wound lap form subwinding as compared to a forward wound lap form subwinding.

9. A poly-phase electromagnetic device having n winding phases (where n is greater than 2), said device including n separate electrical conductor phase windings, each phase winding being made from a single electrical conductor strand; a magnetically conducive base having a plurality of slots adapted to receive active portions of the phase windings therein; each said phase winding comprising a series of spaced active arms that extend through spaced apart non-adjacent slots in the base, each active arm being connected with an end turn or terminal in a continuous wave formation; wherein said phase windings are configured such that an assembly of the phase windings to the magnetically conducive base there is a maximum of n-1 sub-winding end turns overlapping while simultaneously minimising the lengths of the end turns.

10. A device according to claim 7 wherein each phase winding is manufactured as a simple pressing or forged component.

11. A device according to any one of the preceding claims having an axial flux configuration.

12. A device according to any one of the preceding claims having a radial flux configuration.

13. A method of manufacturing a device according to claim 1, 2 or 3 whereby lap form subwindings are wound on separate formers to produce individual "bobbins" which are then stacked into a slotted magnetically conducive base and the bobbin connecting arms electrically joined to form n intertwined phases.

14. A method of manufacturing a device according to claim 1, 2 or 3 whereby a completed n phase winding is formed by direct winding of conductor into the slotted magnetically conducive base.

Dated this 15th Day of November, 2002

IN MOTION TECHNOLOGIES PTY LTD

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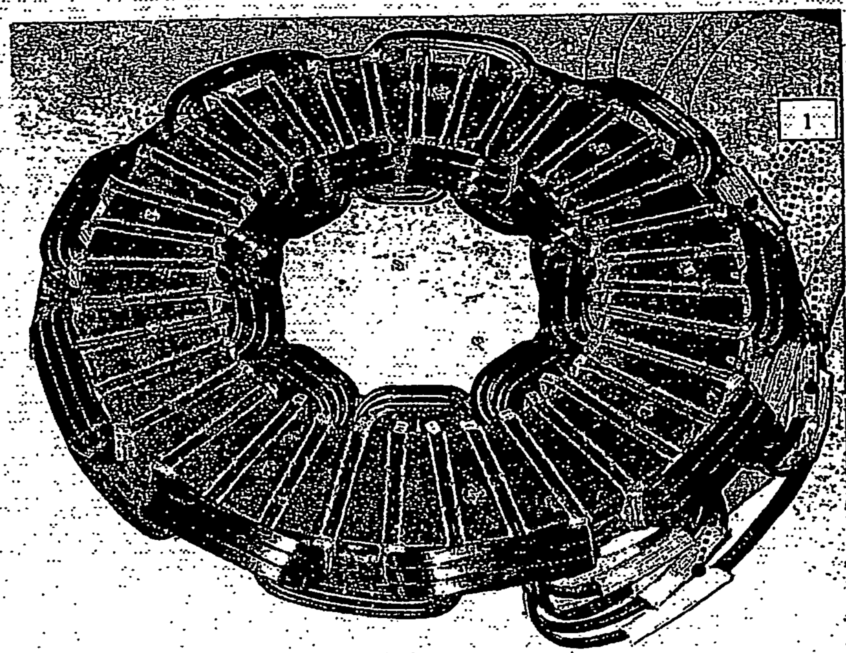

Figure 1

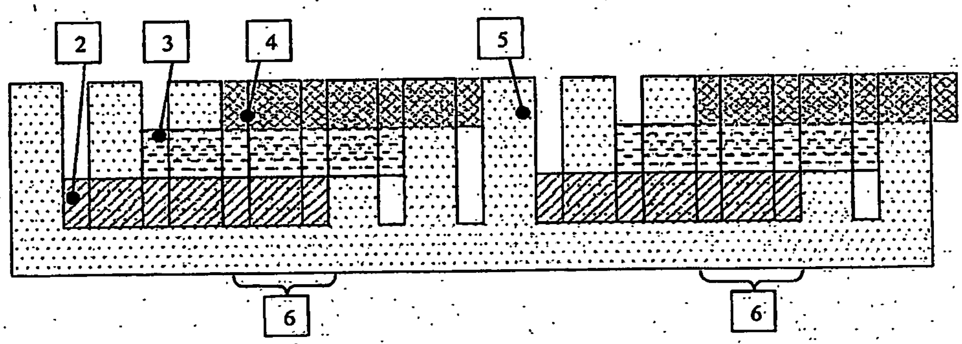

Figure 2

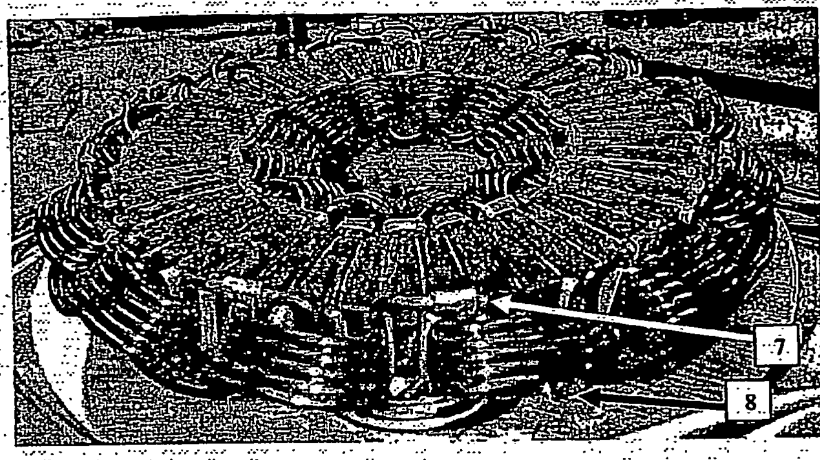

Figure 3

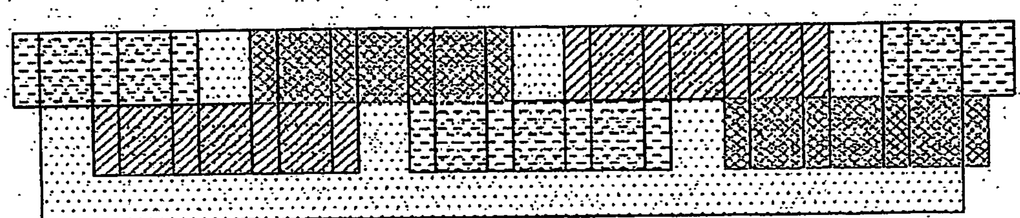

Figure 4

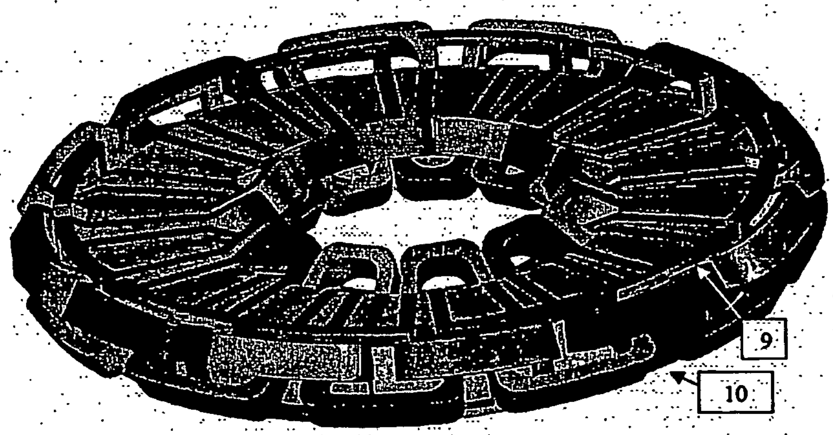

Figure 5

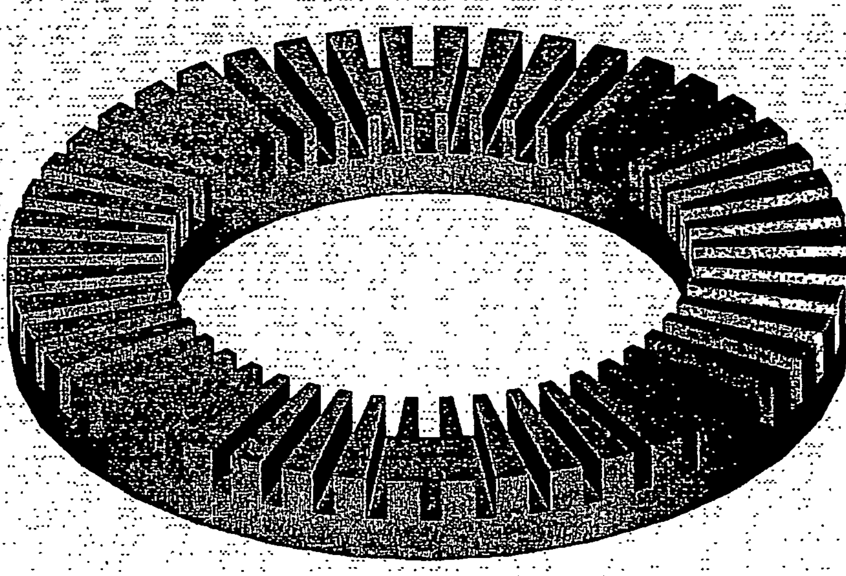

Figure 6

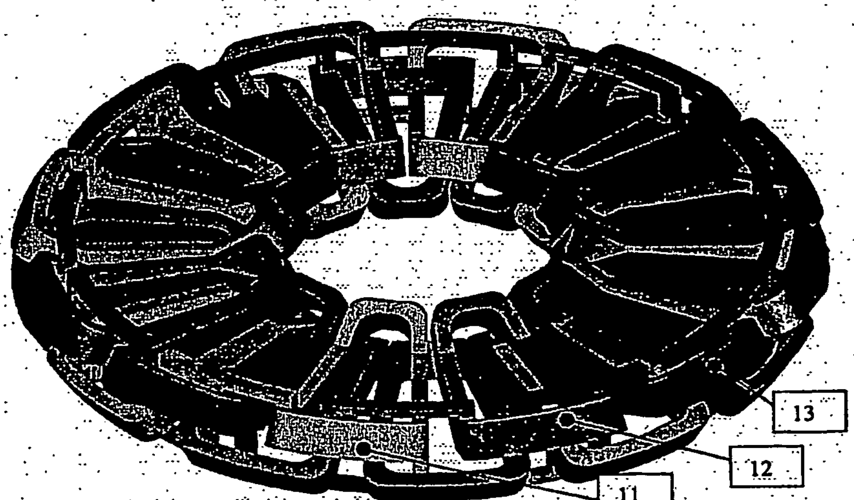

Figure 7

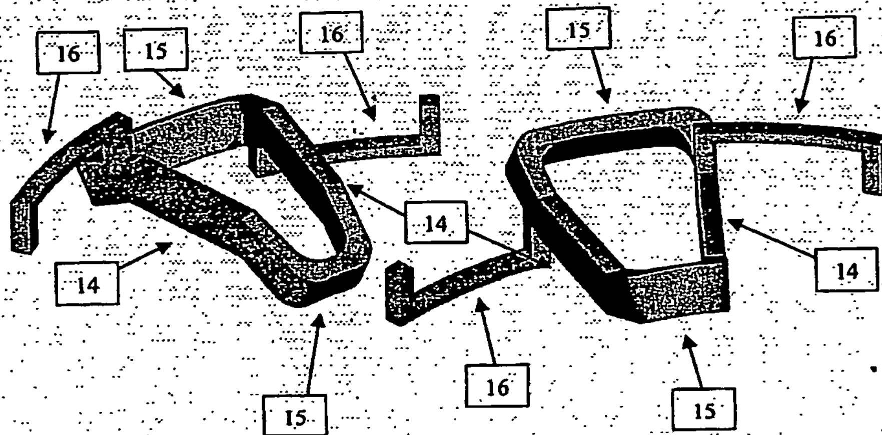

Figure 8

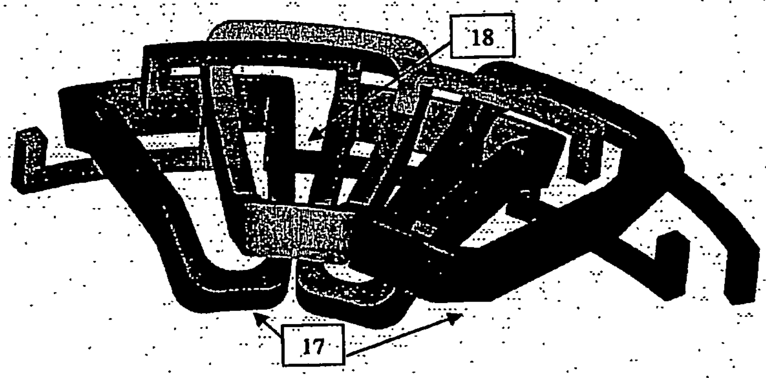

Figure 9

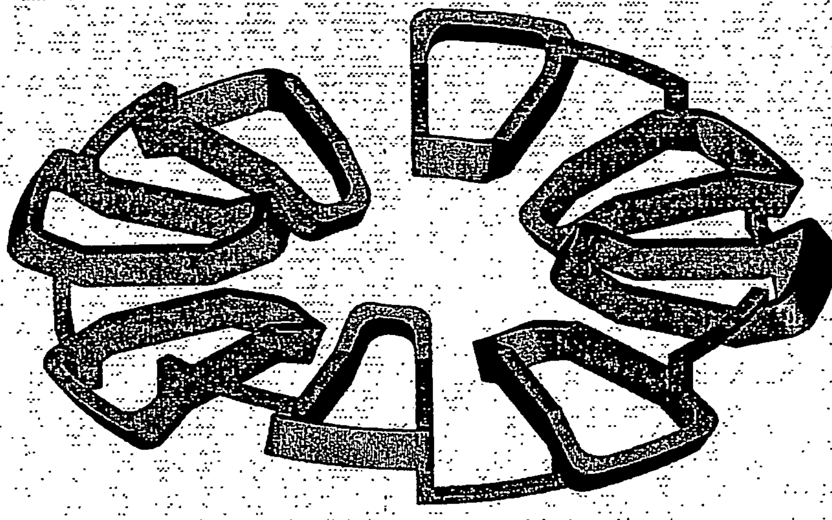

Figure 10

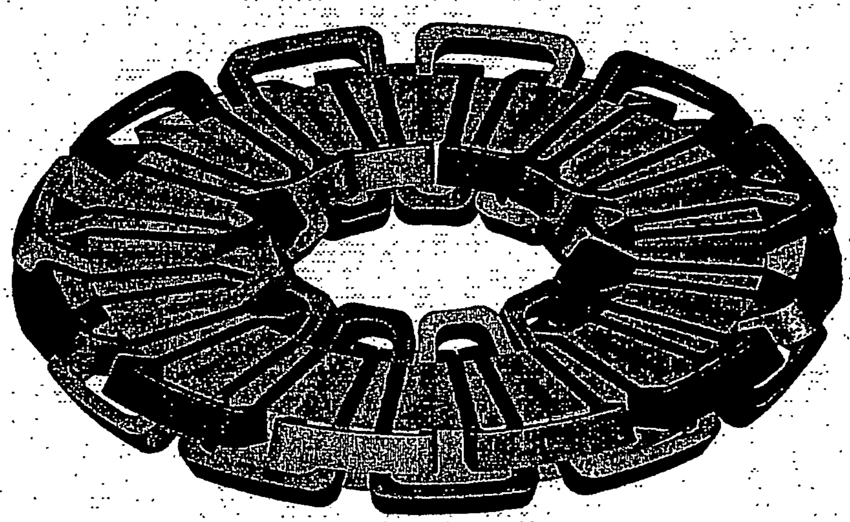

Figure 11

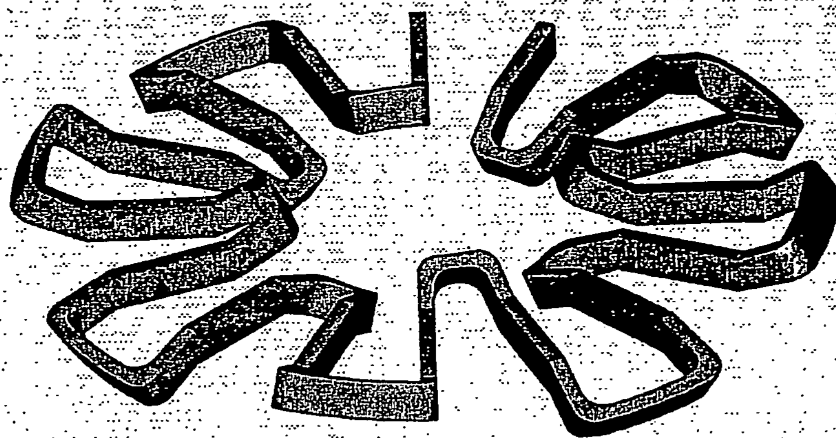

Figure 12